

Plant productivity and characterization of zeoponic substrates after three successive crops of radish

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The National Aeronautics and Space Administration (NASA) has developed advanced life support (ALS) systems for long duration space missions that incorporate plants to regenerate the atmosphere (CO_2 to O_2), recycle water (via evapotranspiration), and produce food. NASA has also developed a zeolite-based synthetic substrate consisting of clinoptilolite and synthetic apatite to support plant growth for ALS systems (Ming et al., 1995). The substrate is called zeponics and has been designed to slowly release all plant essential elements into “soil” solution. The substrate consists of K- and NH_4^+ -exchanged clinoptilolite and a synthetic hydroxyapatite that has Mg, S, and the plant-essential micronutrients incorporated into its structure in addition to Ca and P. Plant performance in zeoponic substrates has been improved by the addition of dolomite pH buffers, nitrifying bacteria, and other calcium-bearing minerals (Henderson et al., 2000; Gruener et al., 2003). Wheat was used as the test crop for all of these studies.

The objectives of this study were to expand upon the previous studies to determine the growth and nutrient uptake of radish in zeoponic substrates and to determine the nutrient availability of the zeoponic substrate after three successive radish crops.

Materials and Methods

Zeoponic substrates (0.5-1.0 mm) consisted of clinoptilolite-rich tuff from the Ft. LeClede deposit in Wyoming, exchanged with either NH_4^+ or K⁺ (Allen et al., 1993), nutrient-substituted hydroxyapatite (Golden and Ming, 1999), and dolomite obtained from Baker Refractories (Gruener et al., 2003). Zeoponic substrate consisted of 36 wt.% NH_4^+ -exchanged clinoptilolite, 36 wt.% K-exchanged clinoptilolite, 18 wt.% synthetic apatite, and 10 wt. % dolomite

Three radish crops were grown successively in the same zeoponic substrate (crops 1, 2, and 3). The experiment was then repeated in a new zeoponic substrate (crops 4, 5, and 6). Two control substrates consisted of peat:vermiculite:perlite potting mix and K-exchanged clinoptilolite. Eight pots per treatment (24 pots total) with 3 plants in each pot were arranged in a randomized block design. Control substrates were watered with $\frac{1}{2}$ -strength Hoagland's solution. Radishes (cv. Cherry Belle) were grown in a controlled environmental plant growth chamber under the following conditions: T=23°C, RH=65%, 16 hour day/8 hour night, and 300 $\mu\text{mol}/\text{m}^2/\text{sec}$ photosynthetic photon flux. Each crop growth cycle was 21 days in length. Fresh and dry weights of shoots, edible storage roots, and fibrous roots and tissue analysis of vegetative parts were determined at the end of each cycle. Exchange cations on clinoptilolite were determined prior to and after growing 3 successive radish crops in the substrate (Ming and Dixon, 1987).

Results and Discussion

Three crops of radish were grown successively in the same zeoponic substrate, and then the procedure was replicated successively with a new zeoponic substrate (Table 1). There were no

significant differences for the fresh weight produced in zeoponic substrates compared to the two control substrates irrigated with nutrient solutions. Zeoponic substrates have the ability to produce radish yields equivalent to substrates that use optimal nutrient solutions.

Table 1. Average fresh weight of the edible roots for radish grown in zeoponic substrates.

Root fresh weight	Zeoponic substrate	Potting mix control substrate	K-clinoptilolite control substrate
-----mass (g)-----			
Crop 1 (ave. of 8 pots)	9.23 (3.52) ^a	18.14 (3.94)	5.04 (3.50)
Crop 2 (ave.)	12.01 (3.43)	11.41 (4.99)	11.72 (3.53)
Crop 3 (ave.)	12.31 (3.61)	9.84 (3.41)	9.61 (2.68)
Average of first 3 crops	11.18 (3.52)	13.13 (4.11)	8.79 (3.23)
Crop 4 (ave.)	4.98 (1.76)	12.40 (5.18)	11.08 (3.30)
Crop 5 (ave.)	11.84 (4.83)	5.70 (3.05)	9.38 (3.01)
Crop 6 (ave.)	15.49 (4.56)	8.08 (2.84)	10.17 (2.84)
Average of second 3 crops	10.77 (3.72)	8.72 (3.69)	10.21 (3.05)
Average of 2 replicates	10.97 (3.62)	10.93 (3.90)	9.50 (3.14)

^aNumbers in parentheses represent one standard deviation.

Plant tissue tests after each 21 day cycle indicated that nutrient uptake was adequate for optimum growth. Prior to plant growth experiments, the NH₄-exchanged clinoptilolite had a NH₄-cation exchange capacity (CEC) of 207 cmol_(c)/kg, and the K-exchanged clinoptilolite had a K-CEC of 202 cmol_(c)/kg. After three successive crops of radish growth, the average NH₄-CEC was 107 cmol_(c)/kg, and the average K-CEC was 158 cmol_(c)/kg. Thus, after three successive crops of radish growth, the zeoponic substrates had 52% of the original NH₄-N and 78% of the original K remaining on zeolite exchange sites, suggesting that zeoponic substrates are capable of long-term, slow-release fertilization for multiple crop cycles.

Conclusions

Radish yields in zeoponic substrates were equivalent to yields in control substrates irrigated with nutrient solutions. Zeoponic substrates also provided all of the plant essential nutrients required for the growth of radish. After three successive crops of growth, the zeoponic substrates had 52% of the original NH₄-N and 78% of the original K remaining on zeolite exchange sites. Zeoponic substrates are capable of long-term, slow-release fertilization for multiple crops.

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